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BIOMASS ESTIMATES OF PACIFIC HERRING, *CLUPEA HARENGUS PALLASI*, IN CALIFORNIA FROM THE 1982-83 SPAWNING-GROUND SURVEYS

by

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ABSTRACT

The spawning biomass of Pacific herring, *Clupea harengus pallasi*, in San Francisco Bay and Tomales Bay was estimated to be 59,000 tons and 11,200 tons, respectively during the 1982-83 season. This represents a 40% decline in San Francisco Bay and a 50% increase in Tomales Bay populations. Unusually high ocean temperatures and record rainfall in California are believed to have affected the distribution and/or survival of herring and caused changes in spawning habits.

1/ Marine Resources Administrative Report No. 83-3.

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INTRODUCTION

In 1973, the California Department of Fish and Game began estimating the annual spawning biomass of Pacific herring, *Clupea harengus pallasi*, in Tomales and San Francisco Bays (Spratt, 1981). Biomass is derived from estimates of eggs deposited during each season. Both bays are relatively small in area and are well suited for intensive spawning-ground surveys. Tomales Bay biomass estimates averaged about 6000 tons from 1973 to 1981, but increased to 7100 tons in 1982 (Spratt, 1982b). The San Francisco Bay estimates began to increase in 1978 as sampling techniques were improved, and the spawning biomass peaked at 100,000 tons in 1982 (Spratt, 1982b).

This report includes spawning biomass estimates for Tomales Bay and San Francisco Bay during the 1982-83 spawning season, and it provides a continuous series of annual herring spawning biomass estimates from 1973-74 onward. These data are the basis of the herring roe fishery management plan.

DESCRIPTION OF STUDY AREA

Tomales Bay

Tomales Bay lies in Marin County, a short distance north of San Francisco. It is 20 km (12.4 miles) long and averages more than 1.5 km (0.9 miles) wide. Hardwick (1973) mapped the distribution and abundance of marine flora in Tomales Bay and found the eelgrass, *Zostera marina*, comprised 75% by weight of all vegetation in the bay. The distribution of eelgrass in Tomales Bay changes slightly each year and the present distribution (Figure 1) was determined during March of 1983. Other species of marine flora are utilized as spawning substrate in Tomales Bay, but eelgrass is the only spawning substrate included in my surveys.

San Francisco

The regular survey area in San Francisco Bay includes all shoreline and shallow subtidal areas to a depth of 4.6 m (15 ft) bounded by the Golden Gate Bridge, Richmond Bridge, and the South Bay to Coyote Point (Figure 2). Spawning in San Francisco Bay is both subtidal and intertidal. Intertidal spawns in San Francisco Bay literally cover all available substrate in the area, including bare rocks, sand, pier pilings, and marine flora. The two major subtidal spawning areas are Richardson Bay and the east bay between Richmond and Oakland. They consist of sparse beds of *Gracilaria* spp. interspersed with *Ulva* sp. and some eelgrass. The only shallow areas consistently not utilized for spawning are broad mud flats with no vegetation.

METHODS

Tomales Bay Sampling Techniques

This season's spawning-ground surveys were conducted from December 2, 1982 to March 15, 1983. Spawn sampling techniques have remained relatively unchanged since 1973 (Spratt, 1981). Every eelgrass bed (Figure 1) was sampled daily from a 4.6-m (15-ft) boat by towing a vegetation sampler through the bed.

The distribution of eelgrass changes yearly; new beds are discovered, old ones disappear, and the areas of some beds change significantly.

Every year in March, after spawning has nearly stopped, the areas of all eelgrass beds are remeasured and these new data are used to calculate all of the season's spawns. Previous estimates of eelgrass density ranging from 0.5-4.0 kg/m^2 (Spratt, 1981) were applied this season to each bed by subjective, on-site inspections.

San Francisco Bay Sampling Techniques

This season's spawning-ground surveys were conducted from November 16, 1982 until March 18, 1983. Techniques used in San Francisco Bay to estimate spawning biomass have evolved over the years (Spratt, 1981), and currently, the major sampling effort is on subtidal spawns, although intertidal (shore-line) spawns still account for a significant part of each season's spawning activity. In order to compute biomass from subtidal spawns, it is necessary to determine the weight (kg/m^2) of vegetation present in the spawning area. Each fall, Department divers collect quantitative samples of vegetation from the bay. The boundaries of known vegetation beds were determined by dragging a vegetation sampler through them. Permanent sampling stations were selected randomly by placing a grid over the beds and numbering points where grid lines intersected. In the east bay 27 stations were selected, and in the Richardson Bay area 24 stations were selected. Divers removed all vegetation from three 0.25-m^2 quadrats at each station. The vegetation was damp-dried and weighed to the nearest gram immediately after collection.

When a subtidal spawn occurred, the vegetation sampler was used to collect samples and determine spawning area (m^2). The number of eggs/kg of vegetation was determined using techniques developed in the 1979-80 season (Spratt, 1981). The estimate of egg deposition is the product of number of eggs/kg vegetation, kg vegetation/m^2, and spawn area (m^2).

In addition to normal intertidal spawning, herring have utilized San Francisco's waterfront pier pilings in both the 1981-82 and 1982-83 seasons. These spawns on pier pilings were sampled in much the same way as a normal intertidal spawn (Spratt, 1981). Sampling sites were selected randomly and 100 sq cm samples of eggs were removed. However, certain problems were encountered that need to be mentioned. Due to the width of most piers, the interior pilings are not accessible and samples had to be taken from pilings

on the perimeter of piers. At most sites it was evident that the interior pilings had heavier egg deposits than pilings near the perimeter. This leads to underestimating the spawn by an unknown degree. It was also difficult to obtain an accurate estimate of the spawning area. The shoreline length was measured following the perimeter of piers and multiplying by three (3) to account for interior pilings. The spawn width could not be measured due to poor sampling conditions (turbidity, currents and wave action). Water depth near most piers averaged 9 m (30 ft) from MLLW and eggs were deposited as high as 2 m (6.6 ft) above MLLW. This range results in a theoretical maximum spawn width of 11 m (36 ft), a width of 7.3 m (24 ft) was used to calculate spawning area. Both the egg density and spawning area estimates are conservative.

Biomass Computation

The methods used to estimate total number of eggs deposited during a season differ between Tomales and San Francisco Bays. However, conversion from numbers of eggs spawned to tons of adults is identical for both bays.

Hardwick's (1973) estimate of fecundity was used to convert numbers of eggs to tons of herring. Hardwick estimated fecundity at 114 eggs/g of herring (both sexes combined) for Tomales Bay herring, and that 103.5 million eggs would be produced by 1 ton of adult herring.

The total eggs deposited during the season is the sum of the estimates of each individual spawn. The number of eggs spawned is converted to short tons of spawners by multiplying by $.966 \times 10^{-8}$, the recriprocal of fecundity per ton of adult herring.

RESULTS

Tomales Bay

There is a total of 32 eelgrass beds in Tomales Bay (Figure 1). Bed measurements in March, 1983 revealed that 3.9 million m^2 (Table 1) of eelgrass were available for spawning during the season.

The first spawn located this season occurred on December 10, 1982, and a total of nine spawning runs was found, that utilized 53 individual spawning sites (Table 2). The number of spawning runs was not unusually high this season, but runs were larger and utilized more individual spawning sites than in recent years.

There was a shift in the timing of spawns this year. For the past 5 yr, over 90% of the season's spawning activity was completed by February first (Spratt, 1982a). In the 1982-83 season, spawning was later, with over half of the season's spawning activity in February and early March (Table 3).

The Tomales Bay population increased in 1983 to the second highest level since the surveys began in 1973. I estimate a minimum spawning escapement of 10,362 tons. The commercial herring roe fishery takes herring just prior to spawning; therefore, the spawning biomass estimate for the season should include the catch. The catch of pre-spawners increased the biomass estimate for the 1982-83 season to 11,184 tons of herring. This is the second consecutive year that the Tomales Bay population has increased significantly (Table 4).

San Francisco Bay

Department divers surveyed subtidal spawning areas of the bay in November 1982 to estimate the density of vegetation. Densities were very low this year, and the east bay area between Oakland and Richmond was not sampled. Richardson Bay had a mean vegetation density of only .040 kg/m^2 (Figure 3) compared with .480 kg/m^2 in 1981 (Spratt, 1982b). Richardson Bay has been the primary subtidal spawning area in the bay during the past two seasons, but with the decline in vegetation densities in 1982, Richardson Bay was relegated to a minor spawning area in the 1982-83 season. The vegetation densities in the two smaller, regularly used, subtidal spawning areas of Belvedere Cove and Kiel Cove were also measured. Vegetation in Belvedere Cove increased to a mean density of .200 kg/m^2, and the mean density in Kiel Cove declined to only .160 kg/m^2 (Figure 3). Another *Gracilaria* spp. bed near Pt. Stuart on Angel Island was also sampled this year, and the mean vegetation density was .347 kg/m^2 (Figure 3). With the exception of Belvedere Cove and the new Angel Island area, the vegetation densities in the bay this season are the lowest since vegetation sampling began in the 1979-80 season.

The first spawn of the season was found on November 7, 1982 at Kiel Cove while diving for vegetation samples. There were at least nine major spawning runs during the season (Table 5). Subtidal spawning was confined to San Francisco Bay (Figure 4), and intertidal spawning was found in both San Francisco Bay (Figure 5) and South San Francisco Bay (Figure 6). Only 26% of the spawning biomass this season was from subtidal spawning as opposed to 77% in the 1981-82 season (Spratt, 1982b). The lack of subtidal vegetation in Richardson Bay caused a change in the spawning habits of herring. The

miles of pier pilings along San Francisco's waterfront were preferred by herring this season over the reduced vegetation in Richardson Bay. The two largest spawns this season were intertidal spawns along the San Francisco waterfront south of the Oakland Bay Bridge (Figure 6) on January 5, 1983 and February 1, 1983. An additional small spawn occurred on January 27. This spawn, at Oyster Point in the South Bay, was not sampled, and therefore, not included in estimates. There were no spawns in the east bay this season.

Spawning was distributed during December, January, and February (Table 6). No spawning was observed in March, although schools of herring were present in the bay.

I estimated spawning escapement at over 49,500 tons of herring. The commercial herring roe fishery catch of pre-spawners was 9695 tons. Including the catch, the spawning biomass for the 1982-83 season was over 59,200 tons, a decline of 40% from 1981-82 (Table 7).

DISCUSSION

Tomales Bay

The Tomales Bay herring population has increased for 2 consecutive yr, and is currently over 11,000 tons, the second highest level recorded. In the 1977-78 season, the Tomales Bay population peaked at 22,000 tons (Spratt, 1981), and the same year the San Francisco Bay population declined to about 8700 tons. In both 1977-78 and 1982-83, high Tomales Bay estimates correlated with low San Francisco Bay estimates. There appears to be a relationship between the two bays, and the population may not be entirely separate. Rainfall reached record or near record amounts both years, and lower salinities in San Francisco Bay may have caused herring in San Francisco Bay to seek alternate spawning areas. Runoff from the delta affects San Francisco Bay salinities much more than runoff into Tomales Bay.

San Francisco Bay

The 1982-83 estimate of the San Francisco Bay herring population declined 40% to 59,200 tons. Record rainfall and abnormally high ocean temperatures (3^{o}-4^{o} F above normal) off California this winter contributed to the low population estimates. If the unusually strong Davidson Current this winter had any affect at all on herring, it would cause a northerly shift in the distribution of the population. This is not a decrease in total stock size, but the result is a decrease in that portion of the population that utilizes San Francisco Bay. If this northerly shift did actually happen, it accounts for the increase in the Tomales Bay population. Record rainfall and runoff caused low surface salinities in San Francisco Bay this winter. This condition may have caused herring to spawn in deep water, where it was undetected by our survey.

Both of these conditions indicate that the San Francisco Bay population may not have declined as much as the 1982-83 population estimate would indicate. If the abnormal environmental conditions this year were the cause of our survey being ineffective, then the San Francisco Bay population could rebound next year if environmental conditions return to normal. If the decline is real and it is the beginning of a downward cycle in the population, next year will be critical to the fishery because quotas will be lowered if the estimate drops below 50,000 tons. Management strategies call for quotas to be set no higher than 20% of the previous season's spawning biomass.

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TABLE 1. Tomales Bay Eelgrass Beds as Measured in March 1983.

Bed number	Area (m^2)	Bed number	Area (m^2)
1	5,500	14	1,400
1A	29,000	15	100
2	10,800	16	42,200
3	4,600	16A	14,600
4	6,000	17	2,200
5	3,500	18	0
6	4,400	19	116,600
7	7,700	20	235,500
8	9,300	20A	55,900
9 North	13,000	21	1,488,000
9 South	17,000	22	140,000
10	4,100	23	1,209,000
11 North	15,400	24	20,900
11 Middle	7,500	25	165,000
11 South	2,600	26	160,000
12	2,400	27	52,000
13	100	28	21,000
		28A	11,800
		TOTAL AREA	3,873,700

TABLE 2. Herring Spawn Data for Tomales Bay, 1982-83 Season.

Date	Location*	Area (m^2)	No. eggs per kg eelgrass	kg eelgrass per m^2	No. eggs per m^2	Millions of eggs	Tons
10 Dec 82	1	5,500	6,600	1.9	12,500	72	1
10 Dec 82	2	5,800	400,000	1.9	760,000	4,408	40
14 Dec 82	1A	6,000	26,000	1.9	49,000	294	3
20 Dec 82	22	31,000	202,000	1.9	384,000	11,904	115
2 Jan 83	1	5,500	259,000	1.9	492,000	2,706	30
2 Jan 83	26	160,000	169,000	1.0	169,000	27,040	260
3 Jan 83	2	10,800	1,073,000	1.9	2,039,000	22,021	215
3 Jan 83	3	4,600	244,000	1.9	464,000	2,134	20
3 Jan 83	4	600	249,000	1.9	474,000	284	3
3 Jan 83	5	3,500	458,000	1.9	870,000	3,045	30
3 Jan 83	6	4,400	513,000	1.9	975,000	4,290	40
3 Jan 83	7	8,100	362,000	1.9	688,000	5,573	55
3 Jan 83	8	9,300	1,086,000	1.9	2,063,000	19,186	185
3 Jan 83	9	31,000	378,000	1.9	718,000	22,258	215
3 Jan 83	11	15,400	381,000	1.9	724,000	11,150	110
5 Jan 83	27	5,200	154,000	1.9	293,000	1,523	15
10 Jan 83	5	3,500	42,000	1.9	80,000	280	3
10 Jan 83	6	4,400	1,169,000	1.9	2,235,000	9,832	95
10 Jan 83	7	8,100	1,042,000	1.9	1,980,000	16,038	155
10 Jan 83	8	9,300	26,000	1.9	49,000	453	5
10 Jan 83	9	31,000	562,000	1.9	1,068,000	33,108	320
24 Jan 83	9	31,000	588,000	1.0	588,000	18,234	175
24 Jan 83	23	60,000	373,000	1.9	709,000	42,540	410
24 Jan 83	24	21,000	230,000	1.9	437,000	9,177	90
24 Jan 83	25	110,000	380,000	1.0	380,000	41,800	400
27 Jan 83	3	4,600	1,028,000	1.9	1,954,000	8,988	90
27 Jan 83	4	600	197,000	1.9	374,000	224	2
27 Jan 83	5	3,500	296,000	1.9	562,000	1,967	20
27 Jan 83	6	4,400	25,000	1.9	48,000	211	2
27 Jan 83	7	8,100	22,000	1.9	418,000	3,385	30
27 Jan 83	8	9,300	30,000	1.0	30,000	279	3
29 Jan 83	22	140,000	246,000	1.9	467,000	65,380	630
31 Jan 83	9	31,000	133,000	1.0	133,000	4,171	40
31 Jan 83	23	480,000	103,000	1.5	154,000	73,920	715
31 Jan 83	25	45,000	463,000	1.0	463,000	20,835	200

* See Figure 1

Table 2 - cont'd.

Date	Location*	Area (m^2)	No. eggs per kg eelgrass	kg eelgrass per m^2	No. eggs per m^2	Millions of eggs	Tons
1 Feb 83	21	92,000	10,000	1.9	19,000	1,748	20
2 Feb 83	10	4,100	43,000	1.9	82,000	336	3
3 Feb 83	1A	29,000	777,000	1.9	1,476,000	42,804	415
13 Feb 83	1	5,500	55,000	1.9	104,000	572	5
13 Feb 83	2	10,800	2,332,000	1.6	3,731,000	40,294	390
13 Feb 83	3	4,600	3,819,000	1.9	7,256,000	33,378	320
13 Feb 83	4	600	1,423,000	1.9	2,704,000	1,622	15
13 Feb 83	5	3,500	898,000	1.9	1,706,000	5,971	60
13 Feb 83	6	4,400	45,000	1.9	85,000	374	4
15 Feb 83	22	125,000	194,000	1.9	369,000	46,125	445
15 Feb 83	23	42,000	117,000	1.9	222,000	9,324	90
15 Feb 83	24	21,000	26,000	1.9	49,000	1,029	10
20-21 Feb 83	21	563,000	405,000	1.5	607,000	342,000	3,300
20-21 Feb 83	23	50,000	18,000	1.1	20,000	1,000	10
2 Mar 83	1A	29,000	471,000	1.9	895,000	25,955	250
2 Mar 83	1	5,500	23,000	1.9	44,000	242	2
3 Mar 83	2	9,800	13,000	1.0	13,000	123	1
6 Mar 83	22	84,000	194,000	1.9	369,000	30,996	300
TOTAL		2,395,300				1,072,603	10,362

*See Figure 1

TABLE 3. Tomales Bay Monthly Herring Spawning Biomass, Expressed as a Percent of Season Total.

	Month			
Season	Dec	Jan	Feb	Mar
1973-74	9	36	55	-
1974-75	10	65	22	3
1975-76	6	68	25	1
1976-77	42	49	5	4
1977-78	5	93	2	-
1978-79	- - - no	survey	conducted - - -	
1979-80	12	86	2	-
1980-81	4	95	1	-
1981-82	3	91	6	-
1982-83	1	45	49	5
Monthly average	10	70	19	1

TABLE 4. Tomales Bay Pacific Herring Spawning Biomass Estimates 1973-74 through 1982-83 Seasons.

Season	Spawn estimate (tons)	Catch (tons)	Spawning biomass (tons)
1973-74	6,041	521	6,562
1974-75	4,210	518	4,728
1975-76	7,769	144	7,913
1976-77	4,739	344	5,083
1977-78	21,517	646	22,163
1978-79	-	448	-
1979-80	5,420	603	6,023
1980-81	5,128	448	5,576
1981-82	6,298	851	7,149
1982-83	10,~~310~~ 362	822	11,184

TABLE 5. San Francisco Bay Herring Spawn Data, 1982-83 Season.

Date	Location	Area (m^2)	No. eggs per kg eelgrass	kg eelgrass per m^2	No. eggs per m^2	Millions of eggs	Tons
7-8 Nov 82	Kiel Cove	67,000	9,640,000	.160	1,543,000	103,000	1,000
22 Nov 82	Belvedere Cove	300,000	1,500,000	.300	450,000	135,000	1,300
23 Nov 82	Tiburon	50,000	*	*	920,000	46,000	440
23 Nov 82	Kiel Cove	67,000	3,400,000	.160	544,000	36,400	350
23 Nov 82	Angel Island	20,000	424,000	.350	148,000	3,000	30
23 Nov 82	Richardson Bay	1,360,000	70,000	.030	2,100	2,800	30
30 Nov 82	Paradise Cove	30,000	300,000	.200	60,000	1,800	20
4-6 Dec 82	Richardson Bay	4,280,000	340,000	.100	34,000	145,000	1,400
6-7 Dec 82	Kiel Cove	67,000	420,000	.160	67,000	4,500	40
7 Dec 82	Angel Island	15,000	32,000	.350	11,000	160	2
7 Dec 82	Tiburon	42,000	*	*	38,000	1,600	15
13-16 Dec 82	Treasure Island	60,000	*	*	2,100,000	126,000	1,200
13-16 Dec 82	Treasure Island	150,000	1,500,000	.200	300,000	45,000	430
21-23 Dec 82	Richardson Bay	3,344,000	74,000	.050	3,700	12,400	120
24-26 Dec 82	Sausalito	215,000	3,337,000	1.0	3,337,000	717,000	6,930
24-26 Dec 82	Sausalito	40,000	*	*	1,727,000	69,000	670
5-8 Jan 83	Treasure Island	115,000	2,825,000	.400	1,130,000	130,000	1,260
5-8 Jan 83	Treasure Island	40,000	*	*	4,600,000	184,000	1,780
9-12 Jan 83	San Francisco	715,000	*	*	1,960,000	1,401,000	13,530
20-21 Jan 83	Tibruon	67,000	*	*	813,000	54,000	520
20-21 Jan 83	Kiel Cove	67,000	12,500	.160	2,000	130	1
1-7 Feb 83	San Francisco	504,000	*	*	2,680,000	1,350,000	13,040
21-22 Feb 83	Belvedere	37,000	*	*	1,900,000	70,300	680
21-22 Feb 83	Belvedere Cove	4,200	2,290,000	.340	993,000	4,170	40
22 Feb 83	Angel Island	47,000	*	*	2,038,000	137,000	1,320
22-23 Feb 83	Sausalito	175,000	*	*	2,000,000	350,000	3,380
	TOTAL	11,989,200				5,129,260	49,548

* These were intertidal spawns and vegetation parameters are not used.

TABLE 6. San Francisco Bay Monthly Herring Spawning Biomass, Expressed as a Percent of Seasonal Total.

	Month				
Season	Nov*	Dec	Jan	Feb	Mar
1973-74	-	8	-	45	47
1974-75	-	1	66	33	-
1975-76	-	12	62	21	5
1976-77	-	18	33	49	-
1977-78	-	52	44	4	-
1978-79	-	14	76	10	-
1979-80	5	72	14	9	-
1980-81	5	36	48	10	1
1981-82	5	24	32	23	16
1982-83	6	22	35	37	-
Monthly average	2	26	41	24	7

* November was not surveyed prior to the 1979-80 season.

TABLE 7. San Francisco Bay Pacific Herring Spawning Biomass Estimates 1973-74 through 1982-83 Seasons.

Season	Spawn estimate (tons)	Catch (tons)	Spawning biomass (tons)
1973-74	4,241	1,938	6,179
1974-75	26,820	514	27,334
1975-76	25,318	1,719	27,037
1976-77	22,375	4,201	26,576
1977-78	3,682	4,987	8,669
1978-79	32,580	4,121	36,701
1979-80	46,439	6,430	52,869
1980-81	59,615	5,826	65,441
1981-82	89,080	10,415	99,495
1982-83	49,548	9,695	59,243

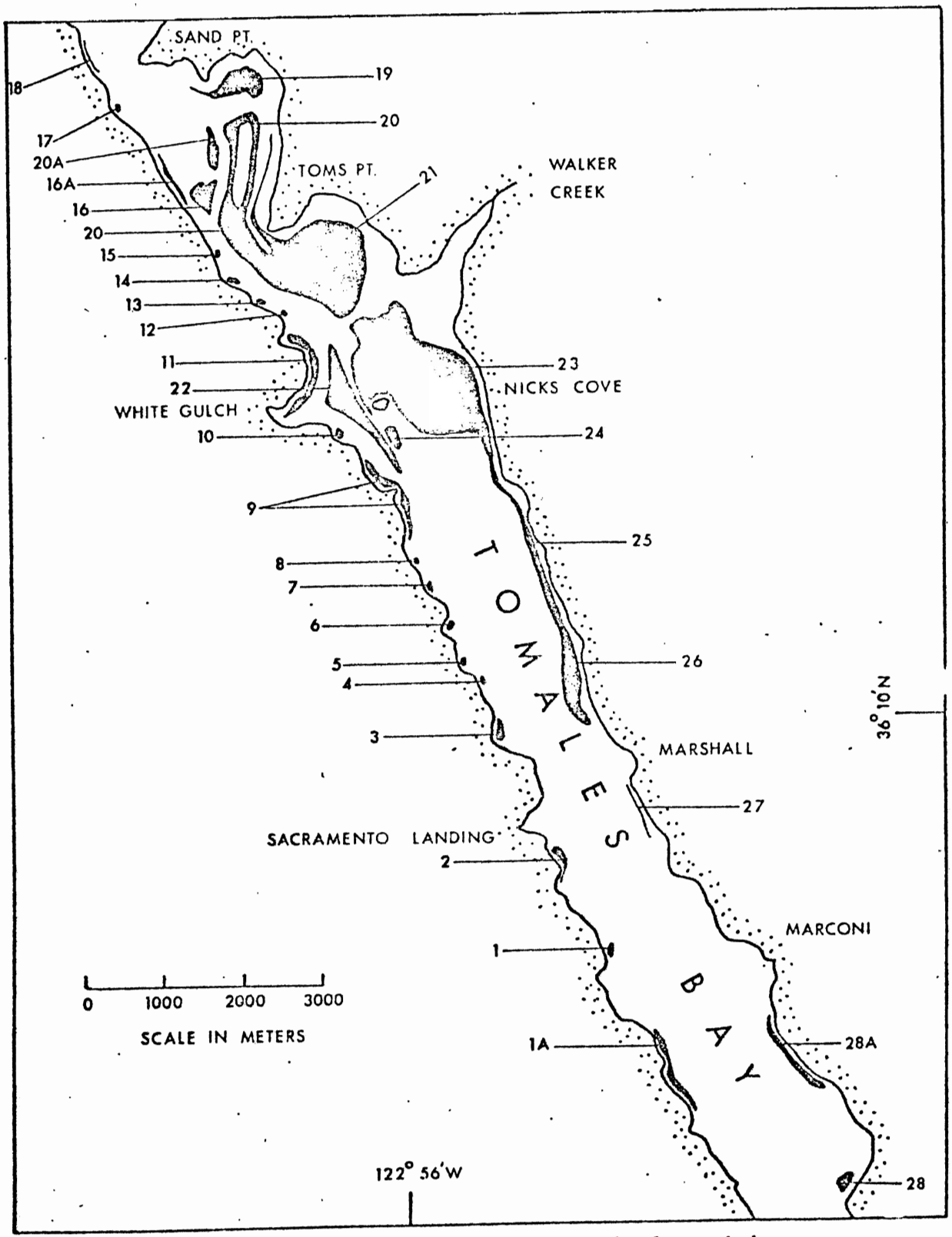

FIGURE 1. Tomales Bay with numbered eelgrass beds.

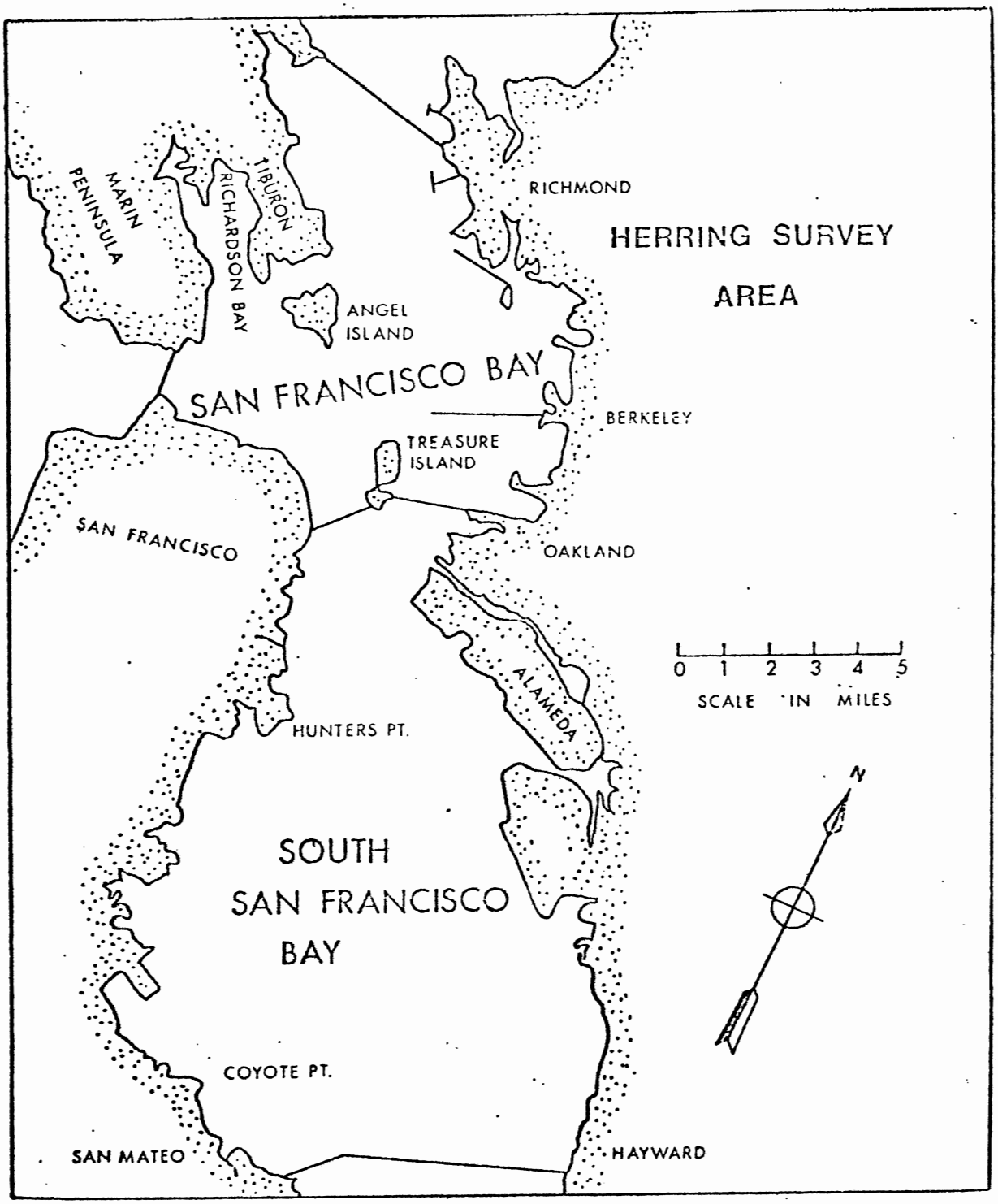

FIGURE 2. Herring spawning-ground survey area in San Francisco Bay.

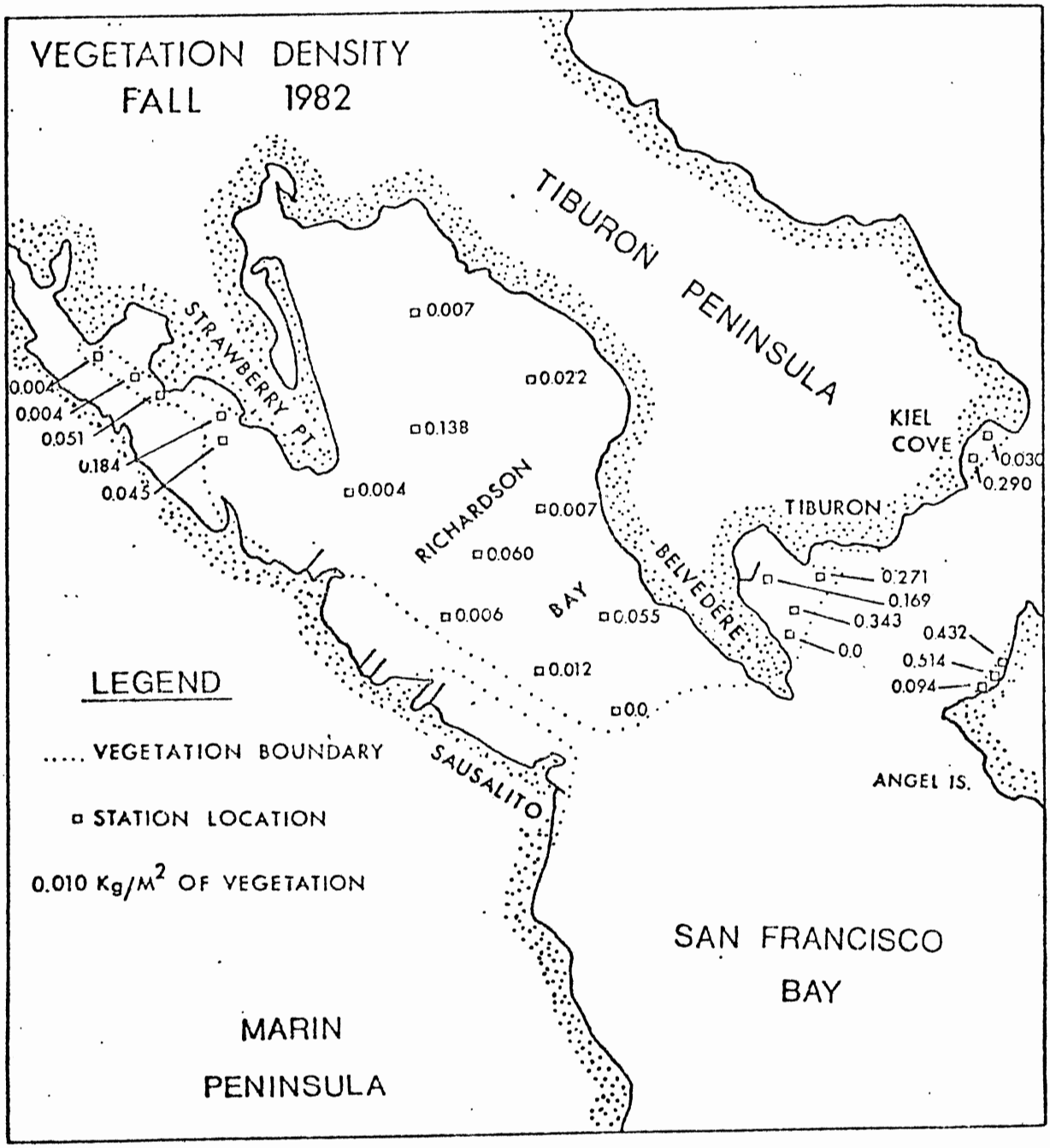

FIGURE 3. Vegetation density kg/m^2 in San Francisco Bay in the fall of 1982.

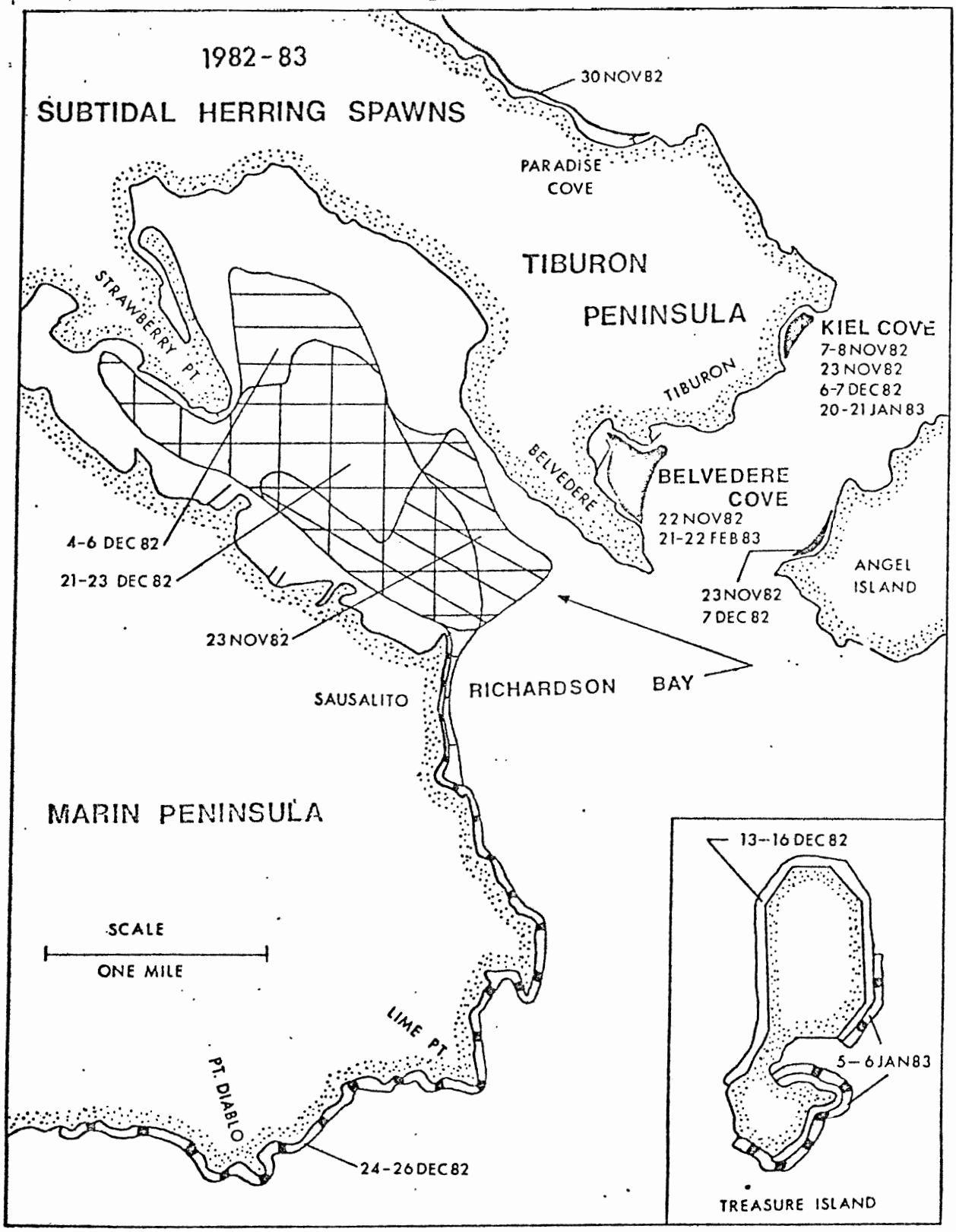

FIGURE 4. Subtidal herring spawnings and dates of occurrence in San Francisco Bay during the 1982-83 season.

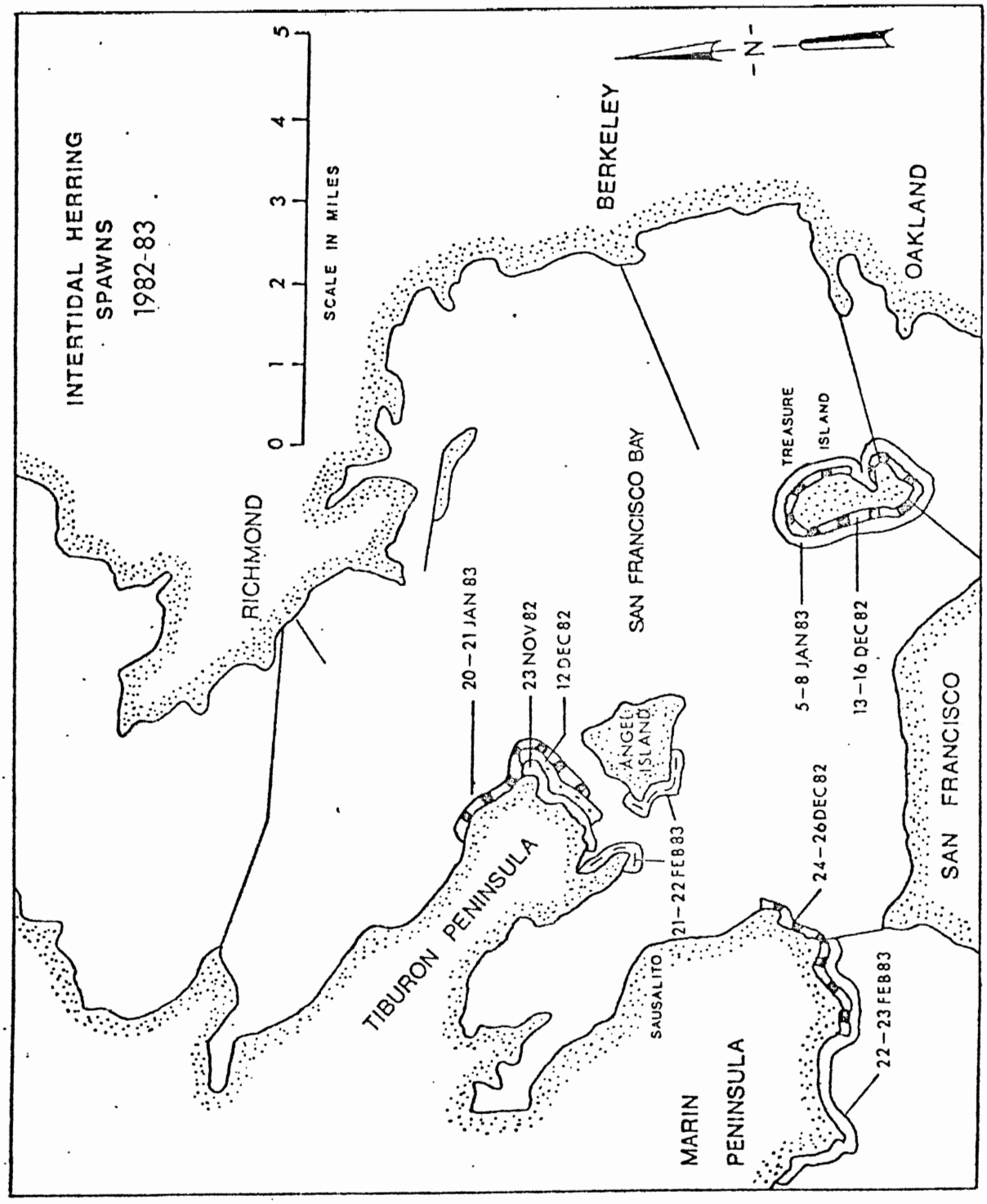

FIGURE 5. Intertidal herring spawnings and dates of occurrence in San Francisco Bay during the 1982-83 season.

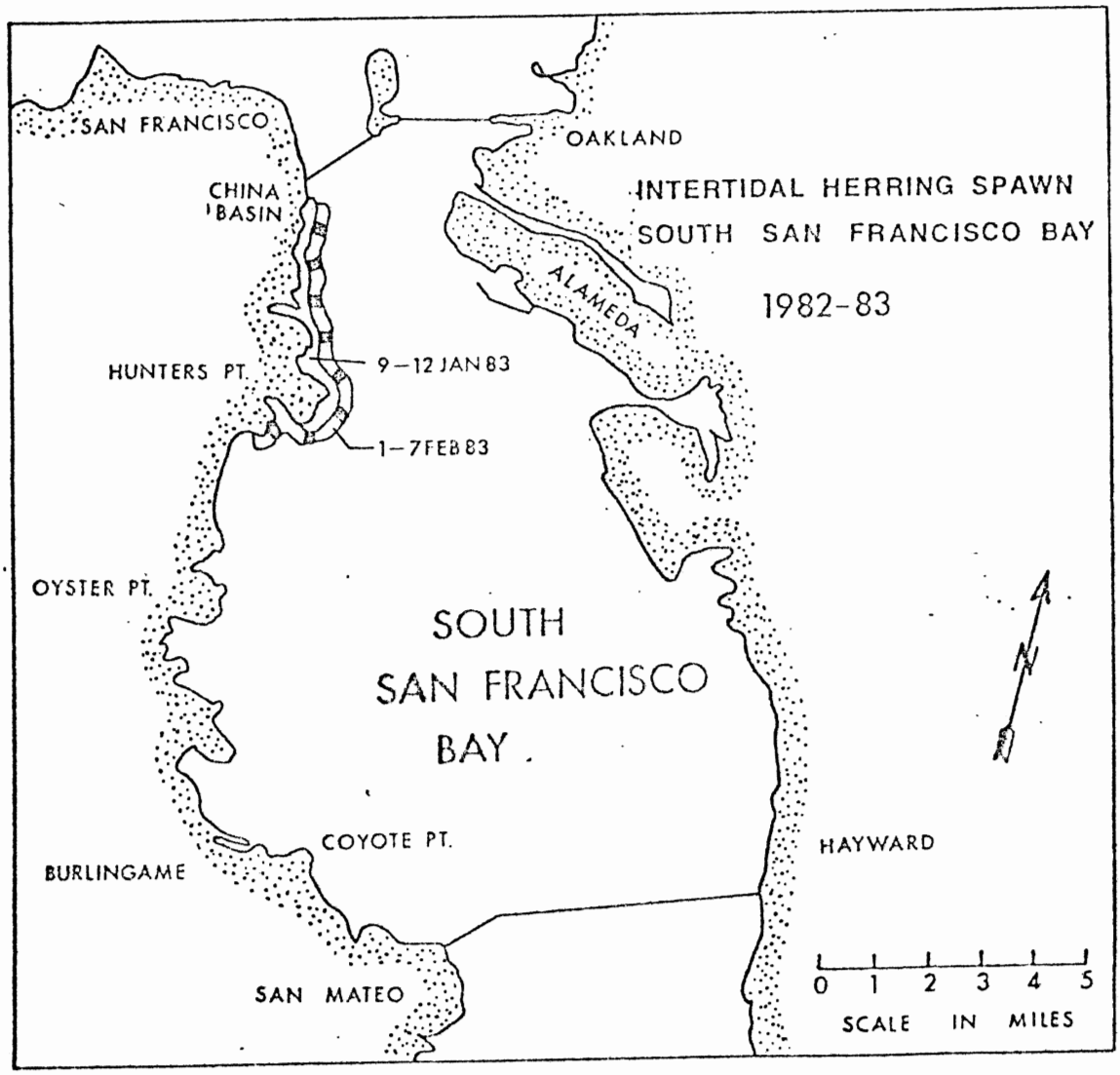

FIGURE 6. Intertidal herring spawning and dates of occurrence in south San Francisco Bay during the 1982-83 season.